CLAIMS

What is claimed is:

1. A method for determining placement of internet taps (ITAPs) in a multi-hop wireless mesh network, wherein the network employs a contention based media access control (MAC) protocol and the network comprises nodes and links between the nodes, the method comprising:

   accepting connectivity information for the network, comprising link capacity constraints, node capacity constraints, node demands for flow, and a set of potential ITAPs to be opened;

   iterating through the set of potential ITAPs to be opened;

   selecting an ITAP, from the set of potential ITAPs to be opened, to be added to a set of currently open ITAPs, wherein the selected ITAP increases the node demands satisfied when opened together with ITAPs in the set of currently open ITAPs;

   adding the selected ITAP to the set of currently opened ITAPs;

   repeating the iterating, selecting, and adding until all the node demands are satisfied; and

   implementing the set of currently opened ITAPs in the network.

2. The method of claim 1 wherein the selecting is repeated until the set of potential of ITAPs to be opened is exhausted and the potential ITAP selected is the potential ITAP which maximizes the node demands satisfied.

3. The method of claim 2 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which maximizes the node demands satisfied comprises:

formulating a max-flow problem, wherein the max-flow problem computes the amount of node demands that can be satisfied under a given set of opened ITAPs when network throughput is independent of network path length;

creating a subgraph induced on a set of nodes, a set of currently opened ITAPs, and a potential ITAP to be opened;

transforming each node's capacity constraint to an edge capacity constraint by replacing each node with a first node and a second node, the first node accepting all incoming edges to the transformed node and all outgoing edges from the transformed node originating from the second node, and creating a directed edge, having the node's capacity, from the first node to the second node;

adding a source node, the source node having edges of capacity equal to the demand of the transformed node from the source to each node in the network;

adding a destination node, the destination node having edges of capacity equal to the capacity of each currently opened ITAP and the potential ITAP to be opened, from each currently opened ITAP and the potential ITAP to be opened to the destination node; and

computing the maximum flow from the source node to the destination node.

4. The method of claim 2 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which maximizes the node demands satisfied comprises:

developing a linear program to compute maximum demands satisfied in the wireless neighborhood network by opening the selected ITAP in conjunction with the set of currently opened ITAPs, wherein the linear program treats throughput of a connection as independent of path length;

modifying the linear program to ensure that flow from each node is served by independent paths;

modifying the linear program to multiply the node demand by the number of independent paths;

modifying the linear program to multiply the capacity constraints by a ratio of an over-provisioning factor to the number of independent paths; and

solving the resulting linear program.

5. The method of claim 2 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which maximizes the node demands satisfied comprises:

finding a shortest path from demand points to opened ITAPs;

routing one unit of flow along the shortest path;

decreasing capacities of edges on the path by one; and

repeating the finding, routing, and decreasing until the shortest path found has a length greater than a hop-count bound.

6. The method of claim 2 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which maximizes the node demands satisfied comprises:

finding a shortest path from demand points to opened ITAPs;

routing one unit of flow along the shortest path;

decreasing capacities of edges on the path by one;

repeating the finding, routing, and decreasing until no path between any demand point and any open ITAP remains; and

computing a demand satisfied along each path according to a throughput function.

7. The method of claim 2 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which maximizes the node demands satisfied comprises:

developing a linear program to compute maximum demands satisfied in the wireless neighborhood network by opening the selected ITAP in conjunction with the set of currently opened ITAPs, wherein the linear program treats throughput of a connection as a function of a number of hops the connection traverses;

denoting an amount of flow routed through an edge based on a position of the edge along a path;

modifying the linear program to limit the maximum flow from each node; and

solving the resulting linear program.

8. The method of claim 2 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which maximizes the node demands satisfied comprises:

developing a linear program to compute maximum demands satisfied in the wireless neighborhood network by opening the selected ITAP in conjunction with the set of currently opened ITAPs, wherein the linear program treats throughput of a connection as a function of a number of hops the connection traverses;

modifying the linear program to ensure that flow from each node is served by independent paths;

modifying the linear program to multiply the node demand by the number of independent paths;

modifying the linear program to multiply the capacity constraints by a ratio of an over-provisioning factor to the number of independent paths; and

solving the resulting linear program.

9. The method of claim 1 wherein the potential ITAP selected is the first potential ITAP which increases the node demands satisfied.

10. The method of claim 9 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which increases the node demands satisfied comprises:

formulating a max-flow problem, wherein the max-flow problem computes the amount of node demands that can be satisfied under a given set of opened ITAPs when network throughput is independent of network path length;

creating a subgraph induced on a set of nodes, a set of currently opened ITAPs, and a potential ITAP to be opened;

transforming each node's capacity constraint to an edge capacity constraint by replacing each node with a first node and a second node, the first node accepting all incoming edges to the transformed node and all outgoing edges from the transformed node originating from the second node, and creating a directed edge, having the node's capacity, from the first node to the second node;

adding a source node, the source node having edges of capacity equal to the demand of the transformed node from the source to each node in the network;

adding a destination node, the destination node having edges of capacity equal to the capacity of each currently opened ITAP and the potential ITAP to be opened, from each currently opened ITAP and the potential ITAP to be opened to the destination node; and

computing the maximum flow from the source node to the destination node.

11. The method of claim 9 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which increases the node demands satisfied comprises:

developing a linear program to compute maximum demands satisfied in the wireless neighborhood network by opening the selected ITAP in conjunction with the set of currently opened ITAPs, wherein the linear program treats throughput of a connection as independent of path length;

modifying the linear program to ensure that flow from each node is served by independent paths;

modifying the linear program to multiply the node demand by the number of independent paths;

modifying the linear program to multiply the capacity constraints by a ratio of an over-provisioning factor to the number of independent paths; and

solving the resulting linear program.

12. The method of claim 9 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which increases the node demands satisfied comprises:
finding a shortest path from demand points to opened ITAPs;
routing one unit of flow along the shortest path;
decreasing capacities of edges on the path by one; and
repeating the finding, routing, and decreasing until the shortest path found has a length greater than a hop-count bound.

13. The method of claim 9 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which increases the node demands satisfied comprises:
finding a shortest path from demand points to opened ITAPs;
routing one unit of flow along the shortest path;
decreasing capacities of edges on the path by one;
repeating the finding, routing, and decreasing until no path between any demand point and any open ITAP remains; and
computing a demand satisfied along each path according to a throughput function.

14. The method of claim 9 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which increases the node demands satisfied comprises:
developing a linear program to compute maximum demands satisfied in the wireless neighborhood network by opening the selected ITAP in conjunction with the set of currently opened ITAPs, wherein the linear program treats throughput of a connection as a function of a number of hops the connection traverses;

modifying the linear program to limit the maximum flow from each node; and
solving the resulting linear program.

15. The method of claim 9 wherein the selecting of the ITAP, from the set of potential ITAPs to be opened, which increases the node demands satisfied comprises:
developing a linear program to compute maximum demands satisfied in the wireless neighborhood network by opening the selected ITAP in conjunction with the set of currently opened ITAPs, wherein the linear program treats throughput of a connection as a function of a number of hops the connection traverses;
modifying the linear program to ensure that flow from each node is served by independent paths;
modifying the linear program to multiply the node demand by the number of independent paths;
modifying the linear program to multiply the capacity constraints by a ratio of an over-provisioning factor to the number of independent paths; and
solving the resulting linear program.

16. A computer-readable medium containing instructions for performing a method for determining placement of internet taps (ITAPs) in a multi-hop wireless mesh network, wherein the network employs a contention based media access control (MAC) protocol and the network comprises nodes and links between the nodes, the method comprising:

accepting connectivity information for the network, comprising link capacity constraints, node capacity constraints, node demands for flow, and a set of potential ITAPs to be opened;

iterating through the set of potential ITAPs to be opened;

selecting an ITAP, from the set of potential ITAPs to be opened, to be added to a set of currently open ITAPs, wherein the selected ITAP increases the node demands satisfied when opened together with ITAPs in the set of currently open ITAPs;

adding the selected ITAP to the set of currently opened ITAPs;

repeating the iterating, selecting, and adding until all the node demands are satisfied; and

implementing the set of currently opened ITAPs in the network.

17. A method for determining placement of internet taps (ITAPs) in a multi-hop wireless mesh network, wherein the network employs a contention based media access control (MAC) protocol and the network comprises nodes and links between the nodes, the method comprising:

accepting connectivity information for the network, comprising link capacity constraints, node capacity constraints, node demands for flow, a set of potential ITAPs to be opened, and a set of time intervals;

iterating through the set of potential ITAPs to be opened;

iterating through the set of time intervals;

for each time interval, computing a total of node demands satisfied by adding an ITAP from the set of potential ITAPs to be opened, to a set of currently open ITAPs;

selecting the ITAP that results in the largest increase in the sum of satisfied node demands over all time intervals;

adding the selected ITAP to the set of currently opened ITAPs;

repeating the iterating, selecting, and adding until the node demands at all time intervals are satisfied; and

implementing the set of currently opened ITAPs in the network.

18. A computer-readable medium containing instructions for performing a method for determining placement of internet taps (ITAPs) in a multi-hop wireless mesh network, wherein the network employs a contention based media access control (MAC) protocol and the network comprises nodes and links between the nodes, the method comprising:

accepting connectivity information for the network, comprising link capacity constraints, node capacity constraints, node demands for flow, a set of potential ITAPs to be opened, and a set of time intervals;

iterating through the set of potential ITAPs to be opened;

iterating through the set of time intervals;

for each time interval, computing a total of node demands satisfied by adding an ITAP from the set of potential ITAPs to be opened, to a set of currently open ITAPs;

selecting the ITAP that results in the largest increase in the sum of satisfied node demands over all time intervals;

adding the selected ITAP to the set of currently opened ITAPs;

repeating the iterating, selecting, and adding until the node demands at all time intervals are satisfied; and

implementing the set of currently opened ITAPs in the network.

19. A method for determining placement of internet taps (ITAPs) in a multi-hop wireless mesh network, wherein the network employs a contention based media access control (MAC) protocol and the network comprises nodes and links between the nodes, the method comprising:

accepting connectivity information for the network, comprising link capacity constraints, node capacity constraints, node demands for flow, a set of potential ITAPs to be opened, and a set of time intervals;

iterating through the set of potential ITAPs to be opened;

selecting an ITAP, from the set of potential ITAPs to be opened, that satisfies the largest node demand;

adding the selected ITAP to the set of currently opened ITAPs, wherein each node's demand is the node's maximum demand over all time intervals;

repeating the iterating, selecting, and adding until the node demands at all time intervals are satisfied; and

implementing the set of currently opened ITAPs in the network.

20. A computer-readable medium containing instructions for performing a method for determining placement of internet taps (ITAPs) in a multi-hop wireless mesh network, wherein the network employs a contention based media access control (MAC) protocol and the network comprises nodes and links between the nodes, the method comprising:

accepting connectivity information for the network, comprising link capacity constraints, node capacity constraints, node demands for flow, a set of potential ITAPs to be opened, and a set of time intervals;

iterating through the set of potential ITAPs to be opened;

selecting an ITAP, from the set of potential ITAPs to be opened, that satisfies the largest node demand;

adding the selected ITAP to the set of currently opened ITAPs, wherein each node's demand is the node's maximum demand over all time intervals;

repeating the iterating, selecting, and adding until the node demands at all time intervals are satisfied; and

implementing the set of currently opened ITAPs in the network.

21. A method for reducing potential placement locations of internet taps (ITAPs) in a multi-hop wireless mesh network by identifying an equivalence class of nodes in the network which are reachable via a wireless link of the network, the method comprising:

accepting connectivity information for the network;

for each node in the network determining the set of nodes by which the node is reachable via the wireless link;

defining an equivalence class as a set of nodes reachable via the wireless link.

22. A computer-readable medium containing instructions for performing a method for reducing potential placement locations of internet taps (ITAPs) in a multi-hop wireless mesh network by identifying an equivalence class of nodes in the network which are reachable via a wireless link of the network, the method comprising:

accepting connectivity information for the network;

for each node in the network determining the set of nodes by which the node is reachable via the wireless link;

defining an equivalence class as a set of nodes reachable via the wireless link.

23. A method for reducing potential placement locations of internet taps (ITAPs) in a multi-hop wireless mesh network by identifying equivalence classes of nodes in the network which may be serviced by the same ITAP, the method comprising:

accepting equivalence class information for the network;

determining whether a first equivalence class is covered by a second equivalence class; and

eliminating the first equivalence class from consideration as a potential placement location for an ITAP if the first equivalence class is covered by the second equivalence class.

24. The method of claim 23 further comprising:

repeating the determining and eliminating until all equivalence classes covered by the second equivalence class have been identified.

25. A computer-readable medium containing instructions for performing a method for reducing potential placement locations of internet taps (ITAPs) in a multi-hop wireless mesh network by identifying equivalence classes of nodes in the network which may be serviced by the same ITAP, the method comprising:

accepting equivalence class information for the network;

determining whether a first equivalence class is covered by a second equivalence class; and

eliminating the first equivalence class from consideration as a potential placement location for an ITAP if the first equivalence class is covered by the second equivalence class.

26. A method for supporting multi-path routing in a multi-hop wireless mesh network, wherein the network employs a contention based media access control (MAC) protocol and the network comprises nodes and links between the nodes, the method comprising:

assigning network traffic, by a source node, to multiple network paths, wherein the assignment is made according to a specified probability;

selecting one of the network paths;

routing the network traffic along the selected path, wherein the source node specifies the end-to-end path; and

forwarding the network traffic, by each intermediate node, wherein the forwarding is done according to the specified path.

27. A computer-readable medium containing instructions for performing a method for supporting multi-path routing in a multi-hop wireless mesh network, wherein the network employs a contention based media access control (MAC) protocol and the network comprises nodes and links between the nodes, the method comprising:

assigning network traffic, by a source node, to multiple network paths, wherein the assignment is made according to a specified probability;

selecting one of the network paths;

routing the network traffic along the selected path, wherein the source node specifies the end-to-end path; and

forwarding the network traffic, by each intermediate node, wherein the forwarding is done according to the specified path.